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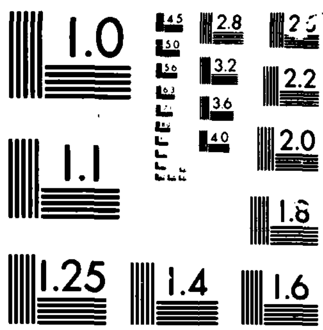

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NPS-61-86-010

NAVAL POSTGRADUATE SCHOOL

Monterey, California

STUDY OF OFF-AXIS RADIATION
ENERGY DEPOSITION FROM 100 MeV
ELECTRONS TRAVERSING THROUGH WATER,
LIQUID NITROGEN AND AIR

By

X. K. Maruyama, F. R. Buskirk, J. R. Neighbours,
R. D. Fitzpatrick, P. F. Cromar and J. E. Mack

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Silver Spring, MD 20903

NAVAL POSTGRADUATE SCHOOL
Monterey, California

Commondore R. H. Shumaker
Superintendent

D. A. Shrady
Provost

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This report ws prepared by:

F R Buskirk
F. R. Buskirk
Professor of Physics

John R Neighbours
J. R. Neighbours
Professor of Physics

X K Maruyama
X. K. Maruyama
Visiting Professor

Approved by:

G E Schacher
G. E. SCHACHER
Chairman, Dept. of Physics

Released by:

J N Dyer
J. N. DYER
Dean of Science and Engineering

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The radiation from the cascade shower of a 100 MeV electron beam in water and LN_2 media has been measured. The measured dose agrees with calculation using the CYLTRAN computer code. Extrapolution to air have been made.

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MEASUREMENT OF OFF-AXIS RADIATION ENERGY DEPOSITION FROM 100 MeV ELECTRONS TRAVERSING WATER, LIQUID NITROGEN AND AIR

X. K. Maruyama,* F. R. Buskirk, J. R. Neighbours,
R. D. Fitzpatrick, P. F. Cromar, and J. M. Mack+

ABSTRACT

The measurements presented here show that calculations are able to predict the dose delivered in a medium in the vicinity of an electron beam. These calculations were done with the CYLTRAN code, but as the physical basis for these and other members of the Integrated TIGER Series is the same, the use of other codes is not expected to provide significant differences. The uncertainties in the physical arrangement in the measurement of the dose do not readily lend themselves to precision experiments, but since the data and calculation agree adequately over many orders of magnitude, any differences cannot be ascribed solely to an inadequacy in the computation.

I. INTRODUCTION

The development of high energy, high current electron accelerators such as the Advanced Test Accelerator[1] has renewed interest in the ability of calculations to predict the radiation exposure in the vicinity of a monodirectional electron beam. The importance of the subject arises not only from personnel safety considerations, but also from vulnerability and lethality considerations in the use of charge particle beam weapons.[2]

There are two series of computational codes in common usage today to calculate electron transport in material. One series has its origins in ETRAN[3] which was originally developed as a tool for solving electron transport problems applied at energies up to a few MeV. ETRAN has been revised and updated with the various codes differing in user friendliness, dimensionality, geometric modeling and elaborateness of ionization/relaxation modeling.[4] These include the TIGER, CYLTRAN, ACCEPT and SANDYL series. The other series which has its origins[5] in cosmic ray physics and considers shower development for very high energy electrons is exemplified by the EGS code system.[6] Both series rely upon Monte Carlo simulation to track the histories of electrons and photons resulting from the electromagnetic cascade shower. Intercomparison[7] of the two series show agreement with each other and with data[3] for GeV primary electrons. In this high energy region, energy transport by photons is the dominant phenomenon and energy transport by electrons is a significant, but relatively minor factor.

These codes address the case where the shower cascade phenomena result from electrons treated as independent particles. This is true for low current density beams or for single event applications. For more intense beams, however, the collective behavior of the electrons becomes important. One study by Geer and Gsponer[9] indicates that for multi-GeV intense electron beams, the radial shower profiles are pinched and the radial spread of the energy deposition from the independent primary particle assumption should be treated as upper limits.

The experimental verification of calculations has been sparse for electron energies near the critical energy, E_c, at which ionization and bremstrahlung processes contribute equally to the energy loss mechanism of the primary electron. This report provides a comparison of data and calculations for 100 MeV electrons in liquid nitrogen and water where the critical energies are 39 and 84 MeV, respectively. Calculations from the CYLTRAN code are capable of predicting the experimental results and provide confidence that independent particle calculations are sufficiently accurate to provide a baseline for further extensions to consider collective effects.

Because these calculations generally require a large amount of computation time, it is useful to have a simple extrapolation procedure to relate one series of experiments or calculations to another where different conditions may exist. We therefore present comparisons between calculations done for air and predictions based on calculations done with LN_2 and H_2O as media.

II. COMPUTATION

The calculation of electron/photon showers was done using the computer code CYLTRAN of the Integrated TIGER Series of transport codes.[4] CYLTRAN is a FORTRAN language time-independent coupled electron/photon Monte Carlo transport code based on the ETRAN model which combines microscopic photon transport with a macroscopic random walk for electron trnansport. The CYLTRAN code is applicable to a cylindrical two dimensional material geometry with three dimensional particle trajectory geometry.

For the case of liquid nitrogen, calculations were performed for longitudinal axis distances of 26, 52, 78 and 104 cm. The number of primary electrons varied from 5000 at 26 cm to 50,000 at 104 cm which kept the statistical uncertainties to about 10% or better. For the case of water and air, 20,000 incident particles were tracked in a single computation. The LN_2 computations were done on a CDC-7600 computer and the H_2O and air computation were done on a Cray computer, both at Los Alamos National Laboratory. Figures 1, 2 and 3 show representations of the calculated normalized dose deposited when initially monodirectional 100 MeV electrons traverse through the media, which were water, liquid nitrogen and air, respectively. To be noted is the significant amount of energy deposited well off of the beam axis. Characteristically, near the entrance of the electron beam into the medium, significant energy deposition occurs only near the beam axis, but as the shower cascade develops, energy deposition is spread perpendicular to the beam axis.

III. MEASUREMENTS

Measurements were conducted at the Naval Postgraduate School using the 120 MeV electron linear accelerator. The incident electron energy was defined by a magnetic deflection system and a set of energy defining slits. The incident electron energy was 100 MeV with energy resolution set to 0.5%. The total charge delivered was determined with a thin foil secondary emission monitor in a vacuum chamber prior to electron beam incidence upon the medium. Determinations of radiation dosage were carried out using calcium fluoride thermoluminescent dosimeters (TLD's) provided and measured by the Naval Surface Weapons Center.

For measurement of the dose delivered in liquid nitrogen, a rectangular container constructed of 1 inch thick, closed cell foam enclosed the medium. Four boxes with interior cross sections of 20 x 20 cm^2 and interior lengths of 26, 52, 78 and 104 cm were used in these measurements. Because the thermoluminescent dosimeters could not be subjected to cryogenic temperatures where possible mechanical failure could occur, the TLDs were attached to the exterior of the beam exit side of the rectangular container in a line perpendicular to the beam axis. In several cases, two rows of TLDs were emplaced, with one set horizontal and the other vertical. The TLDs were encased in 0.3 mil aluminum.

For measurement in water, a single rectangular container of dimension 100 x 46 x 38 cm of 4 mm polyethylene plastic was used to contain the water matrix. This enclosure allowed a useable

test area of 10 cm on either side of the central axis with a minimum of 9 cm of water beyond this to provide a uniform scattering medium with minimal edge effects. The length of the tank allowed measurements to two radiation lengths in water. The dosimeters were mounted on soft wood stretchers at intervals indicated in Figures 4 and 5 and immersed in the water. Since wood contains hydrogen, oxygen, and carbon and is similar to water in average atomic number and weight, it was thought that the use of the wooden stretchers would have negligible effects on the results. The TLDs were enclosed in 1 mil aluminum and were wrapped in a thin plastic film for water tightness.

Phosphor screens placed at the postions of the entrance and exit walls before the media tanks were emplaced defined the beam direction. Exposure was monitored and the TLDs were removed as necessary to insure no detector was over exposed.

Figures 6 through 9 present the results of measurement and calculation for electron beams incident upon a LN_2 matrix. The distances at which the dose was measured are 26, 52, 78 and 104 cm respectively. The radiation length in LN_2 is 47 cm or 39 gm/cm^2. Figures 10 through 13 present the normalized dose measured and calculated for water. The measurement distances are 18.5, 37.0, 55.5 and 74.0 cm. The radiation length in water is 37 cm or 37 gm/cm^2.

The actual uncertainties in these measurements is reflected in the scatter of the data. Contributions to these uncertainties are not precisely quantifiable, however their origins include the

following: the secondary emission monitor has an efficiency which is known to about five percent; the measurement of the dose with thermoluminescent dosimeters is probably no better than five percent; the placement of the dosimeters in the matrix is only good to 0.5 cm; and there is a lack of collinearity of the electron beam. In as much as these measurements span many decades in the magnitude of the measured dose, these uncertainties are not of extreme significance. Conservatively, it is estimated that the measured dose is determined to ± 20%.

IV. INTERMEDIA COMPARISON

For many situations, the interesting medium is air for which experiments are either difficult or impractical because of the large physical distances involved. Measurements of energy deposition are more tractable in a liquid or solid medium where physical distances can be shorter. Therefore, it is convenient to have a simple means by which results in one medium might be applicable to predictions for another medium. Because of the similarities in atomic number and weight and in the radiation length and critical energy for nitrogen, water and air, it is possible to extrapolate quite accurately the results obtained in the liquid media to the gaseous medium. Table I lists some properties of these and some other common substances.[10]

If two detectors subtend the same solid angle and are located at equal distances measured in radiation lengths, the same energy should be deposited in each detector irrespective of the medium. For the case of air, the physical area subtended by

a given solid angle is larger by the square of the ratio of the physical radiation lengths when compared to water or liquid nitrogen. Therefore, the increase in area will result in an increase in the detector mass and hence decrease the dose. Scaling the CYLTRAN calculational results for water or LN_2 by the geometrical ratio of the squares of the radiation lengths for the liquid and the gas provides an approximation for the dose in air as the medium. Figures 14 to 17 shows that this procedure provides an adequate estimation of the dose delivered in air, even out to 1.5 radiation lengths.

Strictly speaking, scaling with radiation length is a very high energy concept applicable when bremstrahlung is the predominant energy loss mechanism for the electron. Near and below the critical energy, the concept of radiation length is not meaningful. The use of the range or density as a scale parameter might be more appropriate. However, it is apparent from Table I that LN_2, water, and air have very similar properties, so that the radiation length is an adequate length parameter. This procedure would not be expected to work for extrapolation between materials differing substantially in average Z and A, e.g., from water to lead.

V. DISCUSSION

The measurements presented here show that calculations are able to predict the dose delivered in a medium in the vicinity of an electron beam. These calculations were done with the CYLTRAN code, but as the physical basis for these and other members of the Integrated TIGER Series is the same, the use of other codes is not expected to provide significant differences. The uncertainties in the physical arrangement in the measurement of the dose do not readily lend themselves to precision experiments, but since the data and calculation agree adequately over many orders of magnitude, any differences cannot be ascribed solely to an inadequacy in the computation.

There has been concern in an earlier report[10] that calculations using CYLTRAN and ETRAN-16 showed substantial differences. However, close scrutiny of the comparison shows that the incident energies of the two calculations differed by a factor of two. Fig. 18 presents curves of the energy deposition per unit depth in a water target irradiated by electrons initially with 60,100 and 125 MeV energies. The 60 and 125 MeV calculations[7] were obtained from an ETRAN code computation and the 100 MeV calculations are from this work calculated using CYLTRAN. The previous concern was that at distances corresponding to a radiation length or greater, normalized dose from the two calculations differed by an order of magnitude. As the dose delivered should track with the energy deposition per unit length, comparison of the 60 MeV and 100 MeV calculations reveal an order of magnitude difference at one radiation length

($37.1\ gm/cm^2$ in H_2O). Furthermore, the 100 MeV CYLTRAN calculation is consistent with the 60 and 125 MeV ETRAN calculation. Consequently, the previous report of discrepancy can be attributed to the differences in the incident electron energy, and not to calculational difficulties.

There are other issues which have not been addressed in this study, which are subjects for future investigation. The measurement of the dose in an environment conducive to precision measurements is a nontrivial task. Among the issues which need better experimental definition is the monodirectionality of the beam. At energies much greater than 100 MeV, the angular beam divergence improves, but at the energies of this experiment, the emittance from available accelerators may not be small enough to ignore. Perhaps studies of this type may require the use of another class of accelerators (i.e., racetrack microtron or synchrotron). We have used CaF_2 dosimeters which have been calibrated with respect to ^{60}Co sources. For precision measurements, the response of the dosimeters to a spectrum expected from high energy electron cascade showers may need to be addressed. The transition from the electron beam source to the transport medium requires an accelerator vacuum - exterior interface. An improved calculation should include the effects of any interface windows and the medium container.

VI. CONCLUSION

The results presented indicate that the CYLTRAN computer code can predict experimental results of the energy deposited off-axis from electron cascade showers. The incident electron energy used in this investigation is near the critical energy, so both ionization and bremstrahlung play important roles. This experiment provides confidence that modern calculations are capable of providing base line single particle interaction model results and can be the basis of extensions with provisions for collective phenomena. The precision of the agreement has limitation from both experimental uncertainties and from statistical limitations in Monte Carlo calculations. However, the general overlap between experiment and calculations extends over several orders of magnitude in response and in more than one medium.

Because of the similarity in properties among LN_2, water and air, a simple prescription for extrapolating from one medium to another is presented. The agreement between predictions from LN_2 and water to calculations in air are as good as comparisons between experiment and calculation with their respective uncertainties.

VII. ACKNOWLEDGMENT

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This report is based on the work[11,12] done as partial requirement for the M.S. in Physics degree of two of the authors (P.F.C. and R.D.F.). This work was done with support from the Naval Surface Weapons Center.

*Permanent Address: National Bureau of Standards
Gaithersburg, MD 20899

+Los Alamos National Laboratory
Los Alamos, NM 87545

REFERENCES

1. W. A. Barletta, "The Advanced Test Accelerator: Generating Intense Electron Beams for Military Applications," Military Electronics/Countermeasures, August 1981, p.21
2. C. M. Huddleston, Naval Surface Weapons Center Technical Report 84-210, 1984 (unpublished)
3. M. J. Berger and S. M. Seltzer, "ETRAN Monte Carlo Code System for Electron and Photon Transport Through Extended Media," CCC-107, Radiation Shielding Information Center, Computer Code Collection, Oak Ridge National Laboratory, June 1986
4. J. A. Halbleib and T. A. Mehlhorn, "ITS: The Integrated TIGER Series of Coupled Electron/Photon Monte Carlo Transport Codes," Sandia Report SAND84-0573, November 1984.
5. B. Rossi, High-Energy Particles, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1952
6. R. L. Ford and W. R. Nelson, "The EGS Code System: Computer Programs for the Monte Carlo simulation of electromagnetic cascade showers," SLAC-210, June 1978
7. S. M. Seltzer and M. J. Berger, "Monte Carlo Studies of Electron and Photon Transport at Energies up to 1000 MeV," National Bureau of Standards Internal Report, NBSIR 78-1534, July 1978
8. C. J. Crannell, H. Cranell, R. R. Whitney and H. D. Zeman, "Electron-Induced Cascade Showers in Water and Aluminum," Physical Rev. 184, 426 (1969)

9. S. Geer and A. Gsponer, "Radiation Dose Distribution Close to the Shower Axis Calculated for High Energy Electrons Initiated Electromagnetic Showers in Air," GIPRI Report, GIPRI-81-06, 10 October 1981

10. M. S. Livingston and J. P. Blewitt, Particle Accelerators, McGraw Hill Book Co., 1962, pp.510-512

11. P. F. Cromar, "Comparison of Calculations and Measurements of the Off-Axis Radiation Dose$^{(Si)}$ in Liquid Nitrogen as a Function of Radiation Length," M.S. Thesis, Naval Postgraduate School, December 1984

12. R. D. Fitzpatrick, "Study of Off-Axis Radiation Exposure from Relativistic Electrons Traversing Through Matter," M.S. Thesis, Naval Postgraduate School, December 1985

TABLE I

VALUES OF RADIATION LENGTH FOR VARIOUS SUBSTANCES

Substance	Z	A	Radiaton lengths (gm/cm2)	(cm)	Critical energy (Mev)
Carbon	6	12	44.6	30.0	102
Nitrogen	7	14	39.4		89
Air	7.4	14.8	37.7	31.0×10^3	84
Water	7.2	14.3	37.1	37.1	84
Oxygen	8	16	35.3		78

FIGURE CAPTIONS

Fig. 1. Plot of dose deposited in a water medium from the cascade shower due to a 100 MeV incident electron beam.

Fig. 2. Plot of dose deposited in a liquid nitrogen medium from the cascade shower due to a 100 MeV incident electron beam.

Fig. 3. Plot of dose deposited in air from the cascade shower due to a 100 MeV incident electron beam.

Fig. 4. TLD positions within the H_2O test tank.

Fig. 5. H_2O test tank dimensions.

Fig. 6. Comparison of the normalized dose from experiment and calculation for LN_2 medium detectors were placed at 26 cm. from the beam entrance to the LN_2 tank. The incident electron energy is 100 MeV.

Fig. 7. Comparison of the normalized dose from experiment and calculation for LN_2 medium. The detectors were placed 52 cm from the beam entrance to the LN_2 tank. The incident electron energy is 100 MeV.

Fig. 8. Comparison of the normalized dose from experiment and calculation for LN_2 medium. The detectors were placed 78 cm from the beam entrance to the LN_2 tank. The incident electron energy is 100 MeV.

Fig. 9. Comparison of the normalized dose from experiment and calculation for LN_2 medium. The detectors were placed 104 cm from the beam entrance to the LN_2 tank. The incident electron energy is 100 MeV.

Fig. 10. Comparison of the normalized dose from experiment and calculation for H_2O medium. The detectors were placed 18.5 cm from the beam entrance of the H_2O tank. The incident electron energy is 100 MeV.

Fig. 11. Comparison of the normalized dose from experiment and calculation for H_2O medium. The detectors were placed 37 cm from the beam entrance of the H_2O tank. The incident electron energy is 100 Mev.

Fig. 12. Comparison of the normalized dose from experiment and calculation for H_2O medium. The detectors were placed 55.5 cm from the beam entrance of the H_2O tank. The incident electron energy is 100 MeV.

Fig. 13. Comparison of the normalized dose from experiment and calculation for H_2O medium. The detectors were placed 74 cm from the beam entrance of the H_2O tank. The incident electron energy is 100 MeV.

Fig. 14. Comparison of normalized dose in air predicted from LN_2 and H_2O media calculations and from calculations using air as the medium. The dose is for a distance of 77 m from the beam entrance.

Fig. 15. Comparison of normalized dose in air predicted from LN_2 and H_2O media calculations and from calculations using air as the medium. The dose is for a distance of 154 m from the beam entrance.

Fig. 16. Comparison of normalized dose in air predicted from LN_2 and H_2O media calculations and from calculations using air as the medium. The dose is for a distance of 307 m from the beam entrance.

Fig. 17. Comparison of normalized dose in air predicted from LN_2 and H_2O media calculations and from calculations using air as the medium. The dose is for a distance of 461 m from the beam entrance.

Fig. 18. Energy deposition per unit depth in a water target irradiated by electron beams with incident energies of 60,100 and 125 MeV. The results are normalized to one incident electron. The 60 and 125 MeV curves were calculated[7] with the Monte Carlo Code ETRAN. The 100 MeV curve is from this work calculated using CYLTRAN.

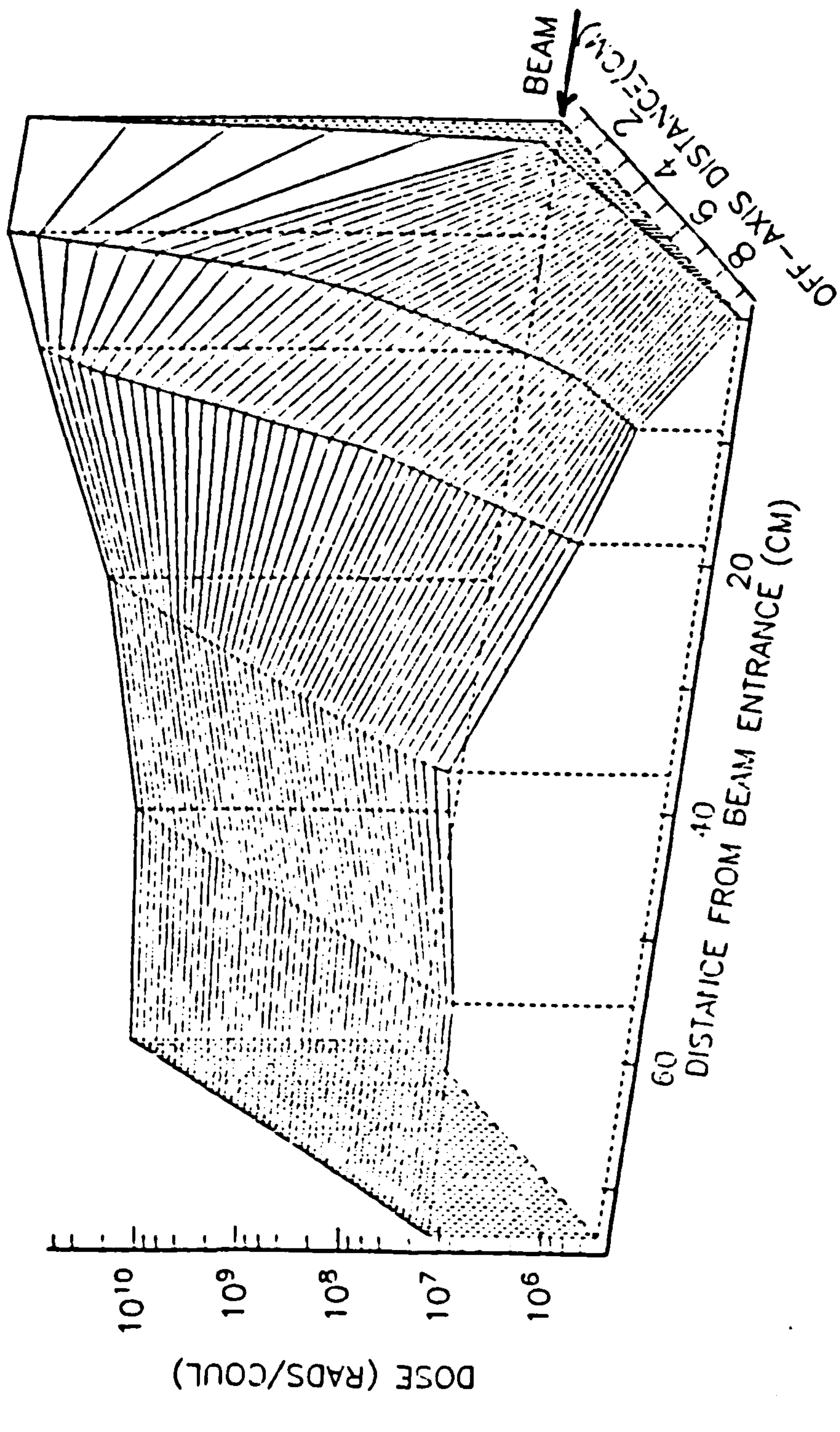

BEAM
OFF-AXIS DISTANCE (CM)
2
4
6
8
DISTANCE FROM BEAM ENTRANCE (CM)
20
40
60
DOSE (RADS/COUL)
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}

Figure 1

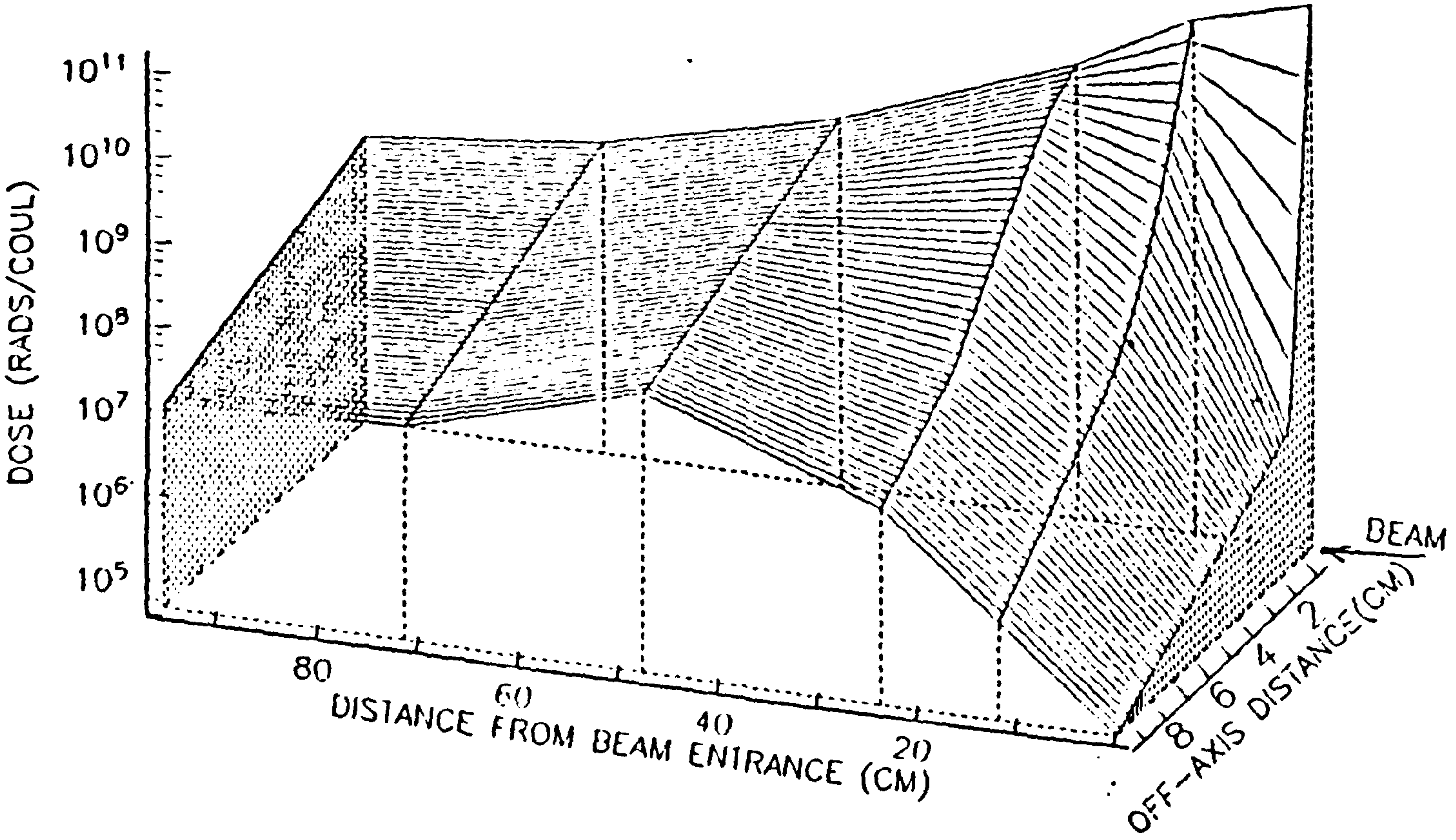
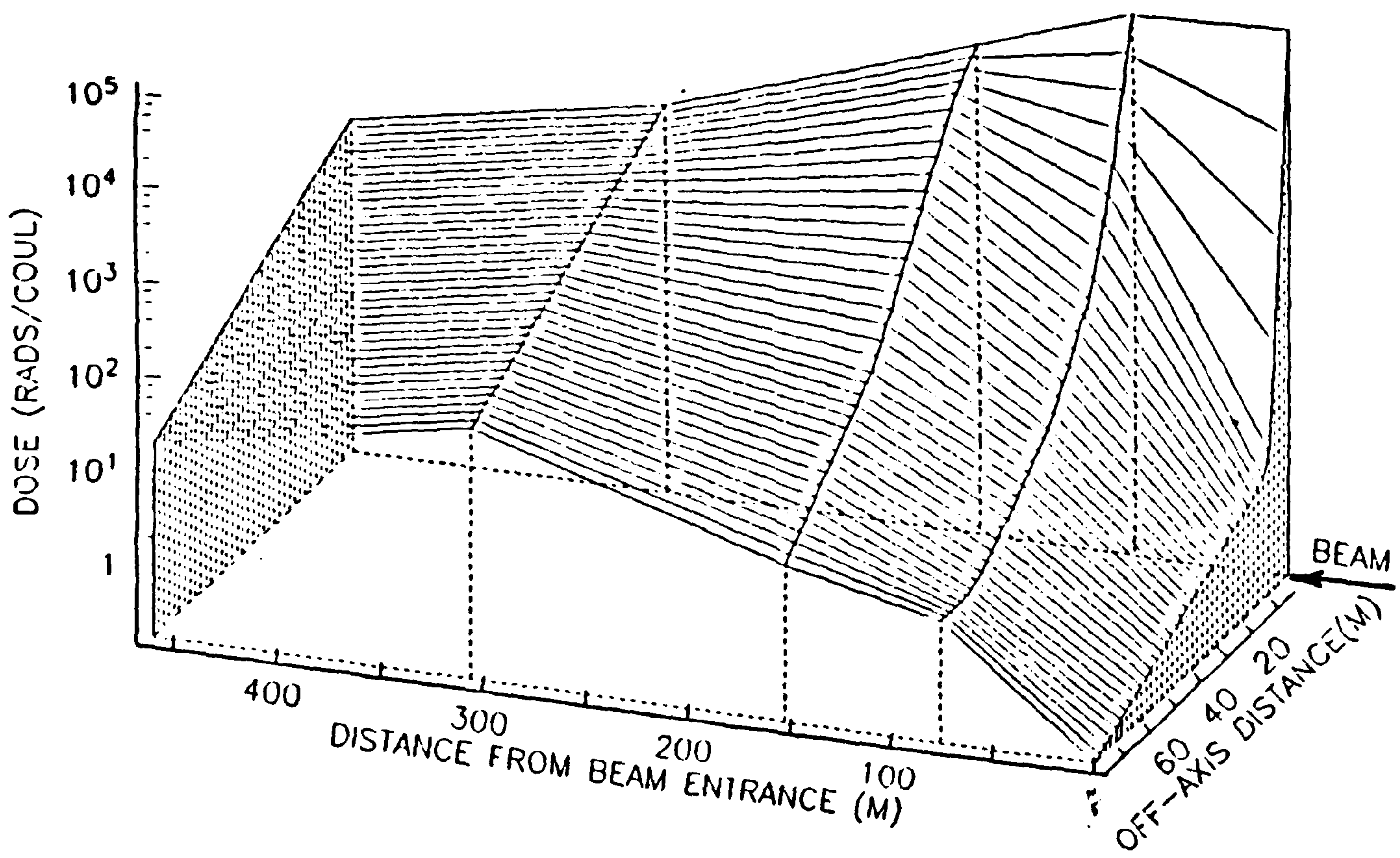
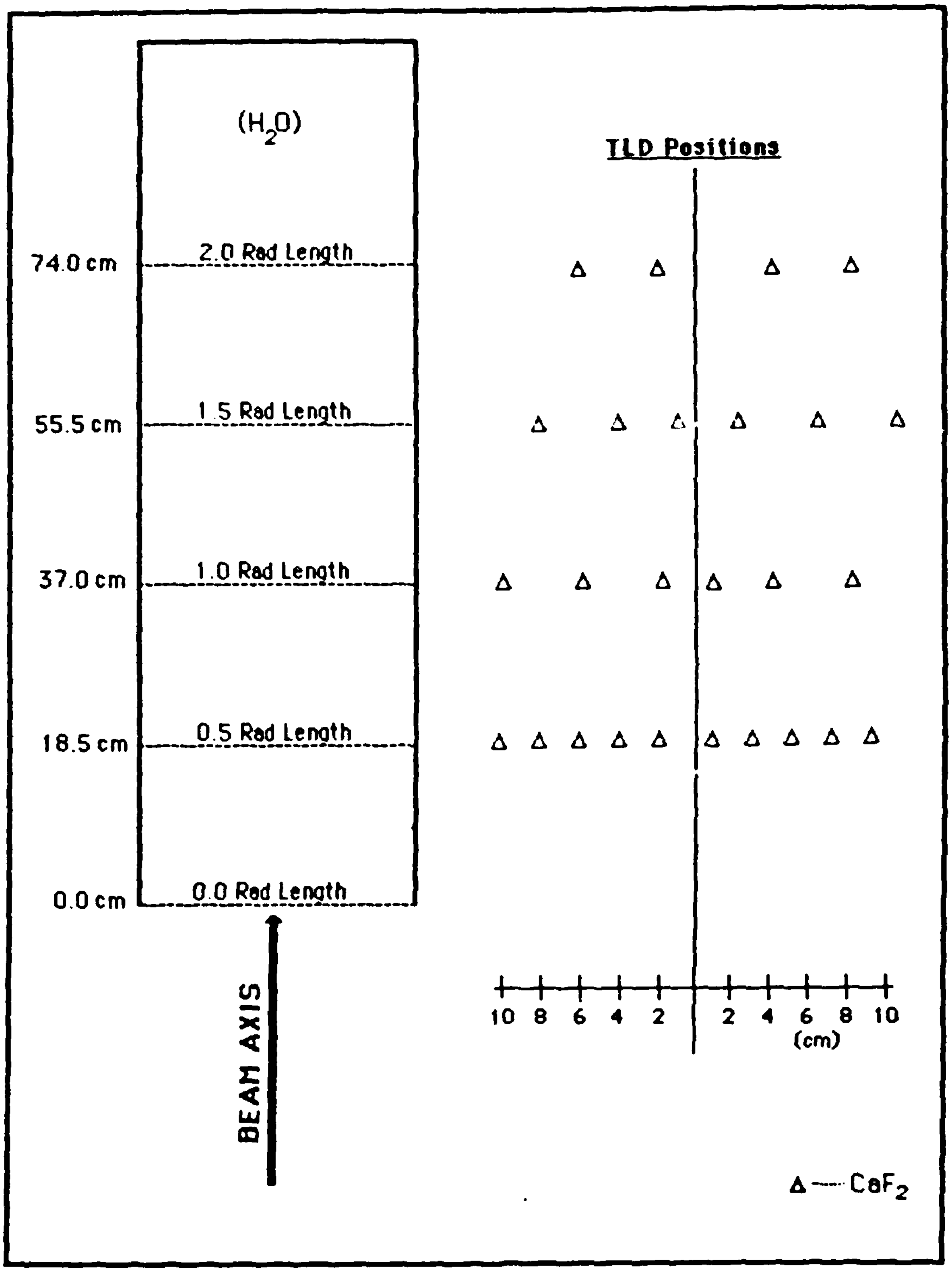

DOSE (RADS/COUL)
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
80
60
40
20
DISTANCE FROM BEAM ENTRANCE (CM)
BEAM
2
4
6
8
OFF-AXIS DISTANCE(CM)

Figure 2



DOSE (RADS/COUL)
10^5
10^4
10^3
10^2
10^1
1
400
300
200
100
DISTANCE FROM BEAM ENTRANCE (M)
60 40 20
OFF-AXIS DISTANCE(M)
BEAM

Figure 3



(H_2O)
TLD Positions
74.0 cm
2.0 Rad Length
55.5 cm
1.5 Rad Length
37.0 cm
1.0 Rad Length
18.5 cm
0.5 Rad Length
0.0 cm
0.0 Rad Length
BEAM AXIS
10 8 6 4 2 2 4 6 8 10
(cm)
Δ — CaF_2

Figure 4

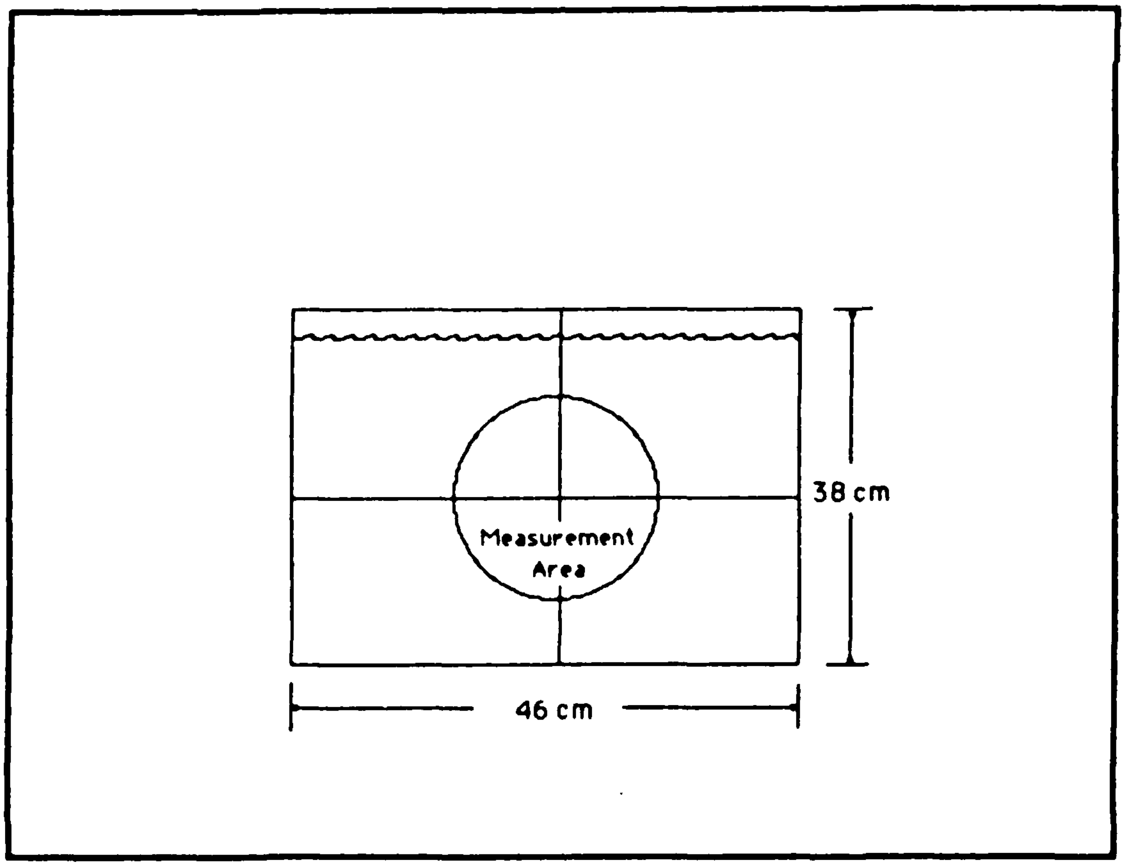


Figure 5

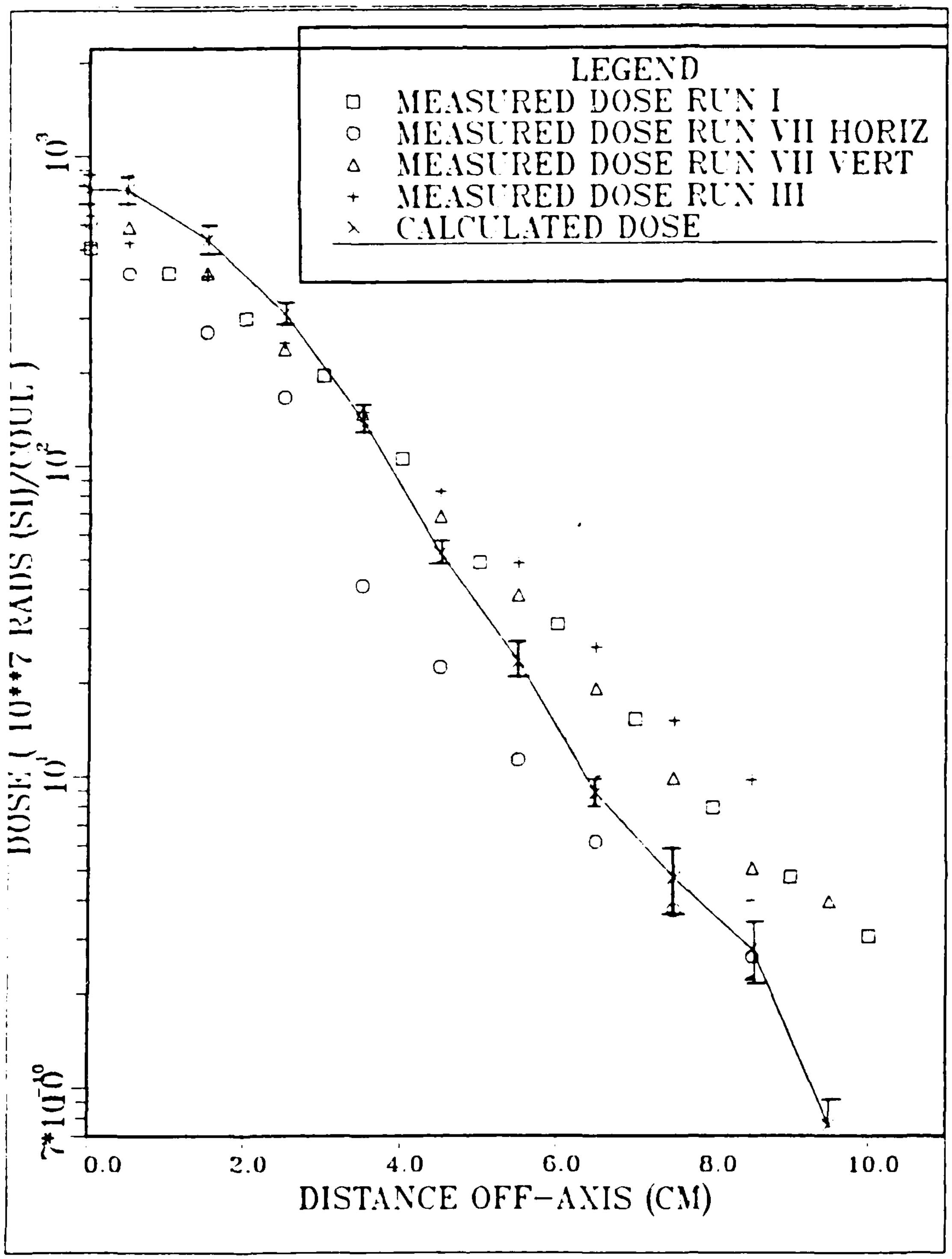

LEGEND
MEASURED DOSE RUN I
MEASURED DOSE RUN VII HORIZ
MEASURED DOSE RUN VII VERT
MEASURED DOSE RUN III
CALCULATED DOSE
DOSE (10**7 RADS (SI)/COUL)
DISTANCE OFF-AXIS (CM)
0.0
2.0
4.0
6.0
8.0
10.0

Figure 6

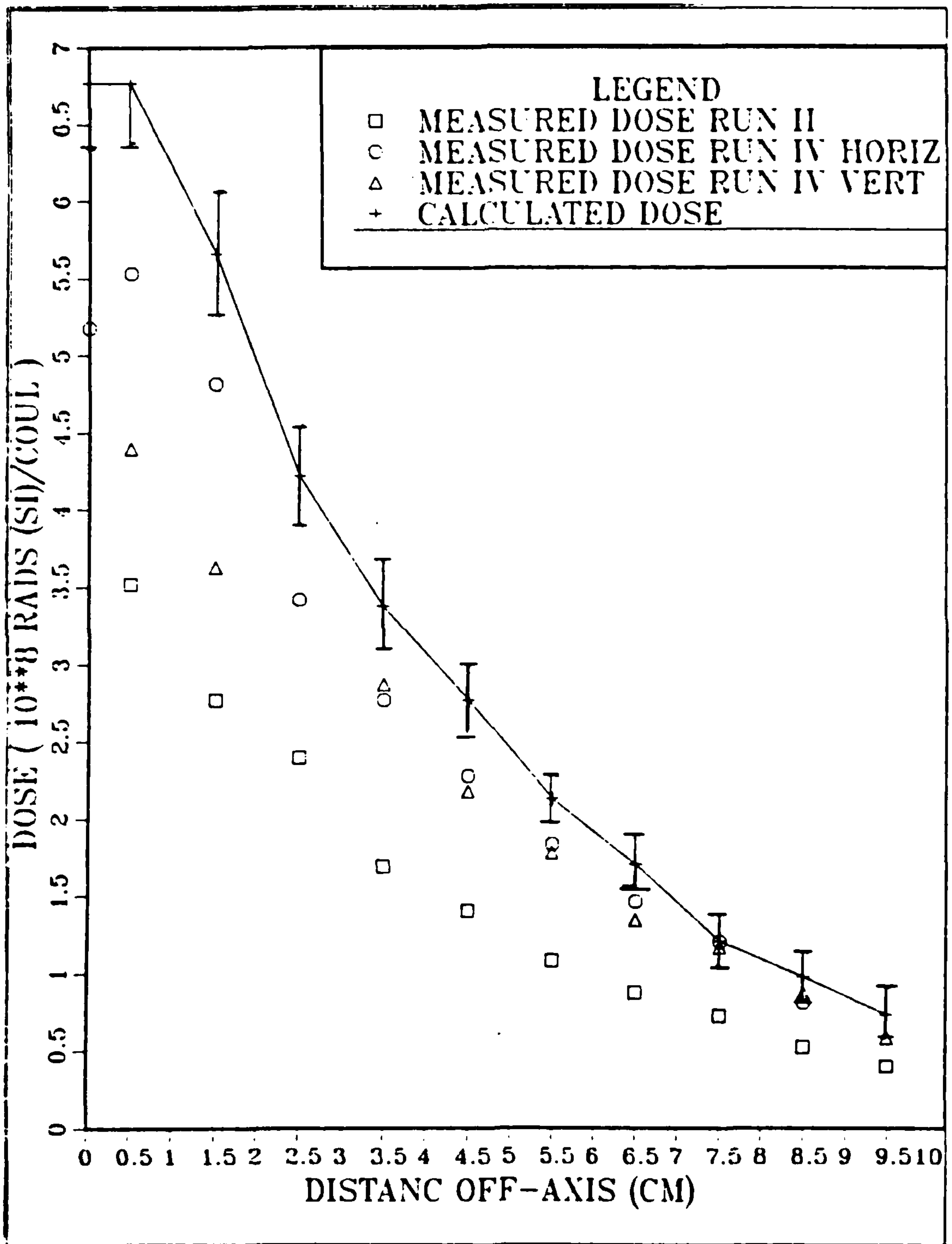

LEGEND
MEASURED DOSE RUN II
MEASURED DOSE RUN IV HORIZ
MEASURED DOSE RUN IV VERT
CALCULATED DOSE
DOSE (10**8 RADS (SI)/COUL)
DISTANC OFF-AXIS (CM)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10

Figure 7

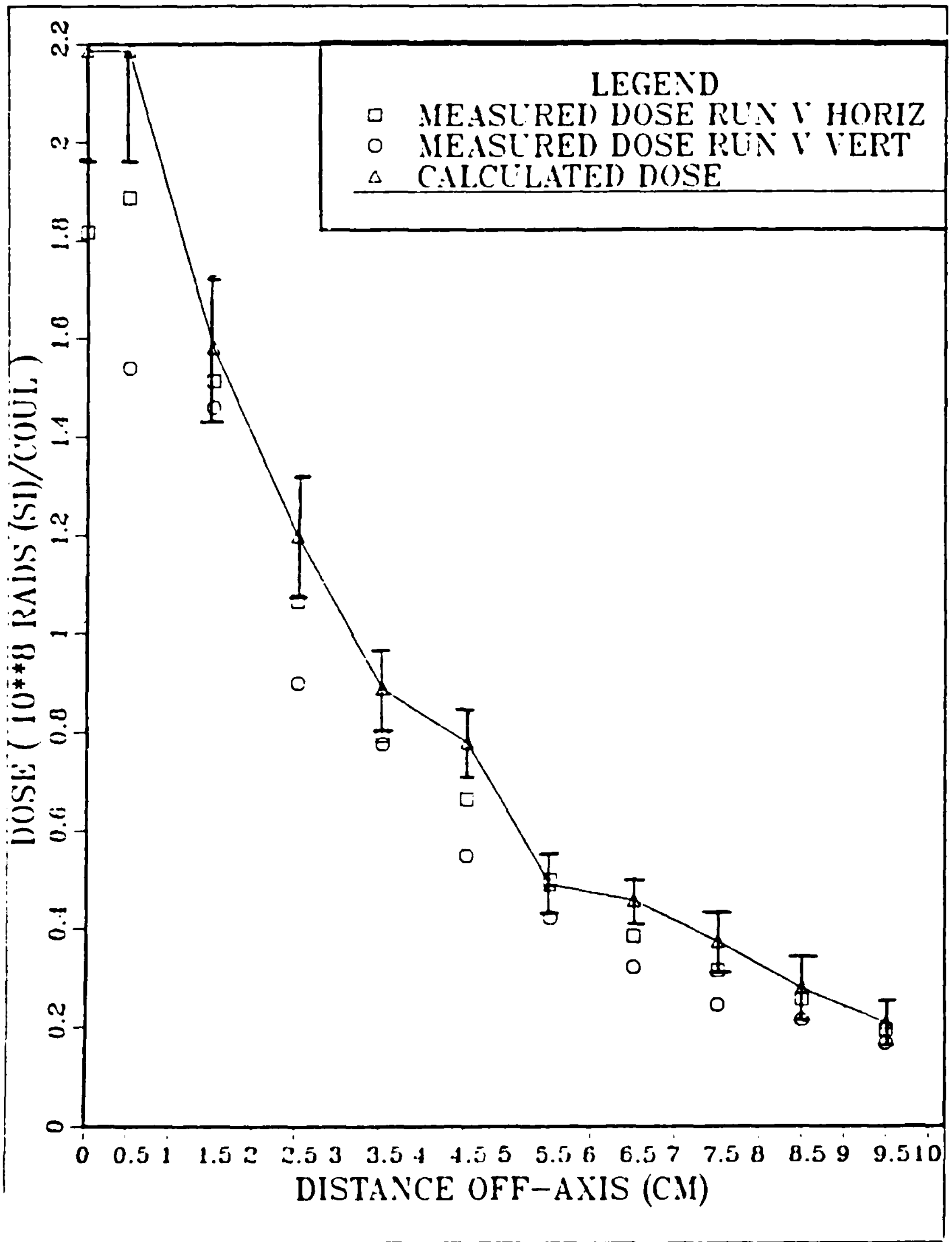

LEGEND
MEASURED DOSE RUN V HORIZ
MEASURED DOSE RUN V VERT
CALCULATED DOSE
DOSE (10**8 RADS (SI)/COUL)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
DISTANCE OFF-AXIS (CM)

Figure 8

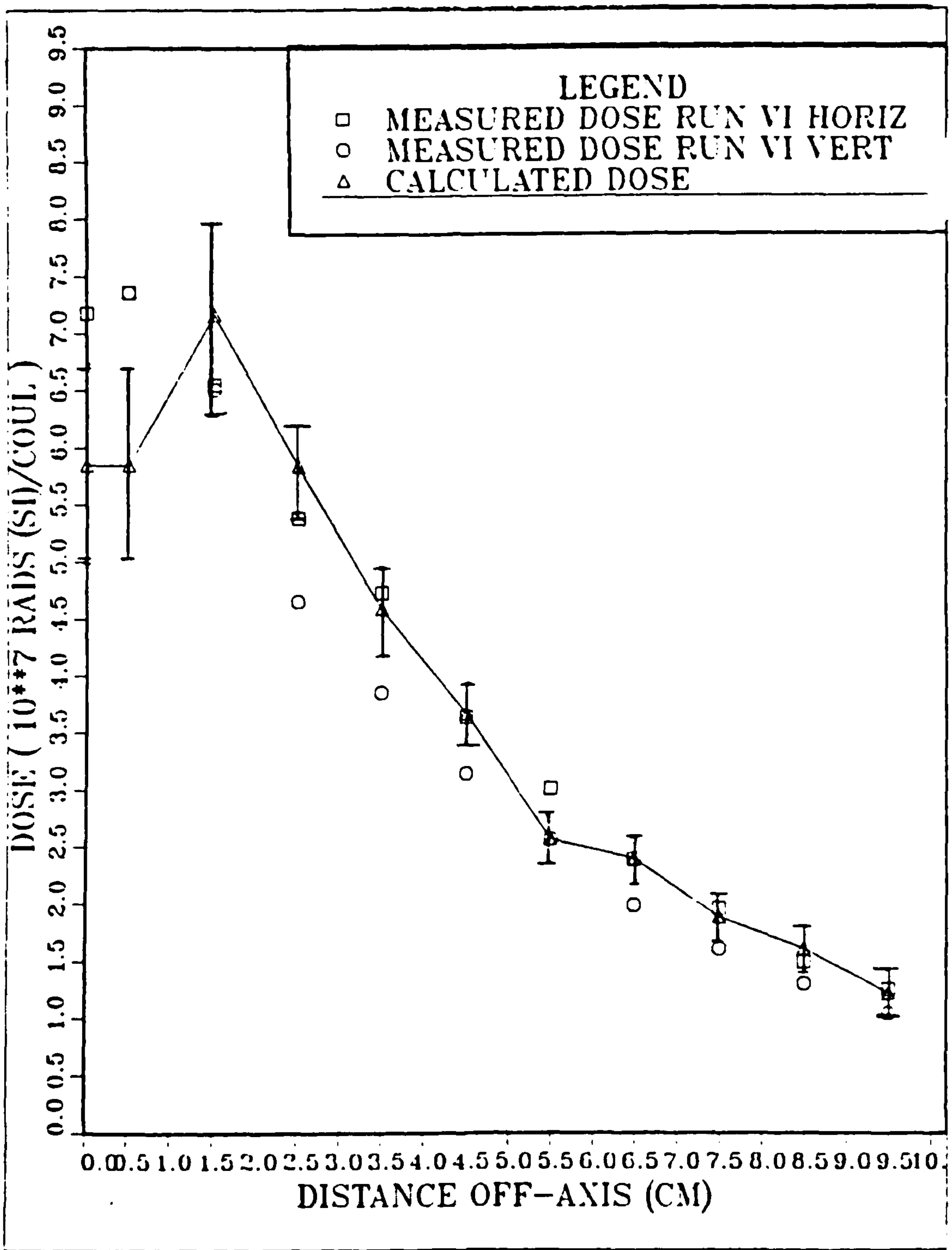
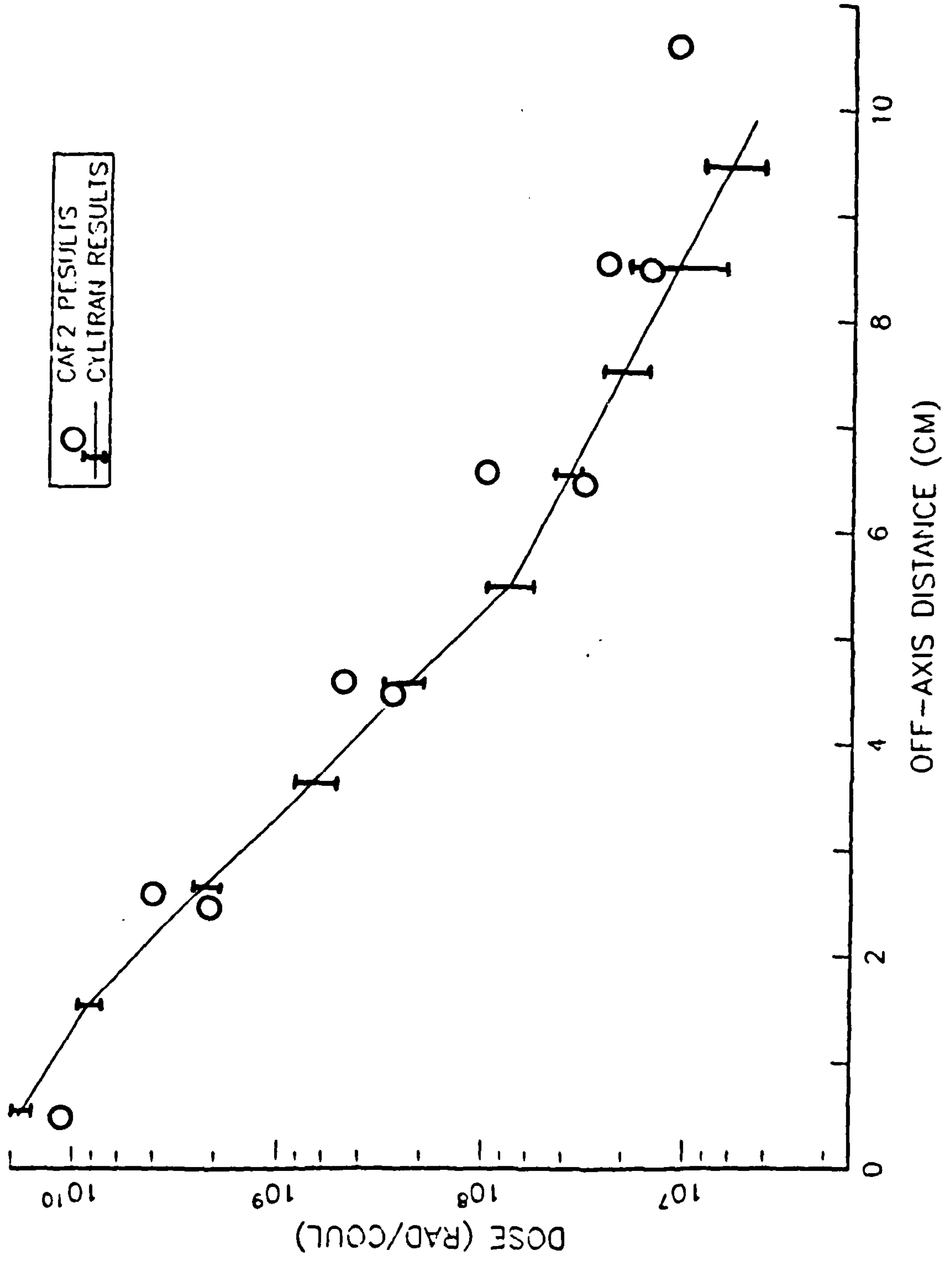

LEGEND
MEASURED DOSE RUN VI HORIZ
MEASURED DOSE RUN VI VERT
CALCULATED DOSE
DOSE (10**7 RADS (SI)/COUL)
DISTANCE OFF-AXIS (CM)

Figure 9



CAF2 RESULTS
CYLTRAN RESULTS
OFF-AXIS DISTANCE (CM)
DOSE (RAD/COUL)
0
2
4
6
8
10
10^{10}
10^{9}
10^{8}
10^{7}

Figure 10

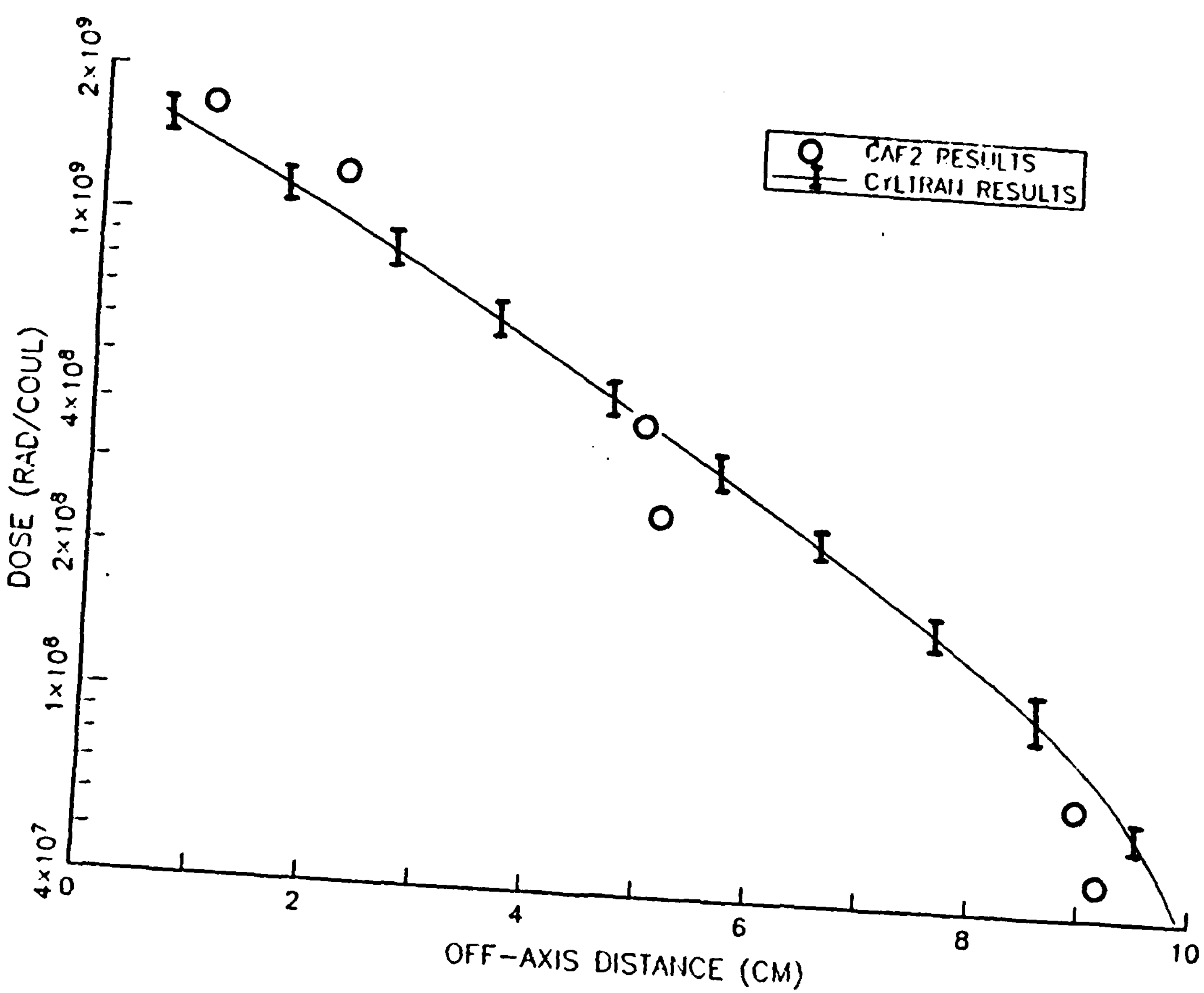

CAF2 RESULTS
CYLTRAN RESULTS
DOSE (RAD/COUL)
2×10⁹
1×10⁹
4×10⁸
2×10⁸
1×10⁸
4×10⁷
0
2
4
6
8
10
OFF-AXIS DISTANCE (CM)

Figure 11

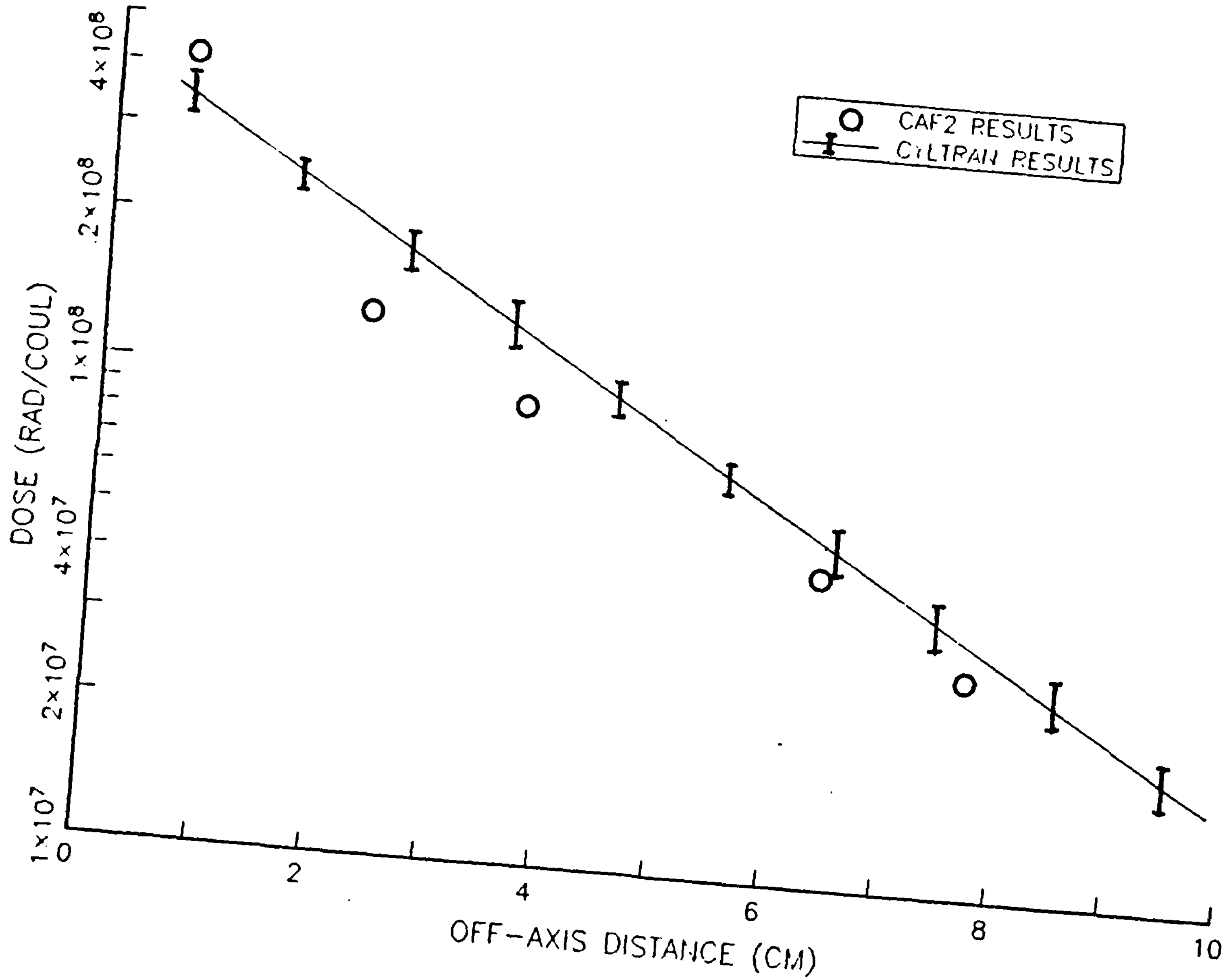
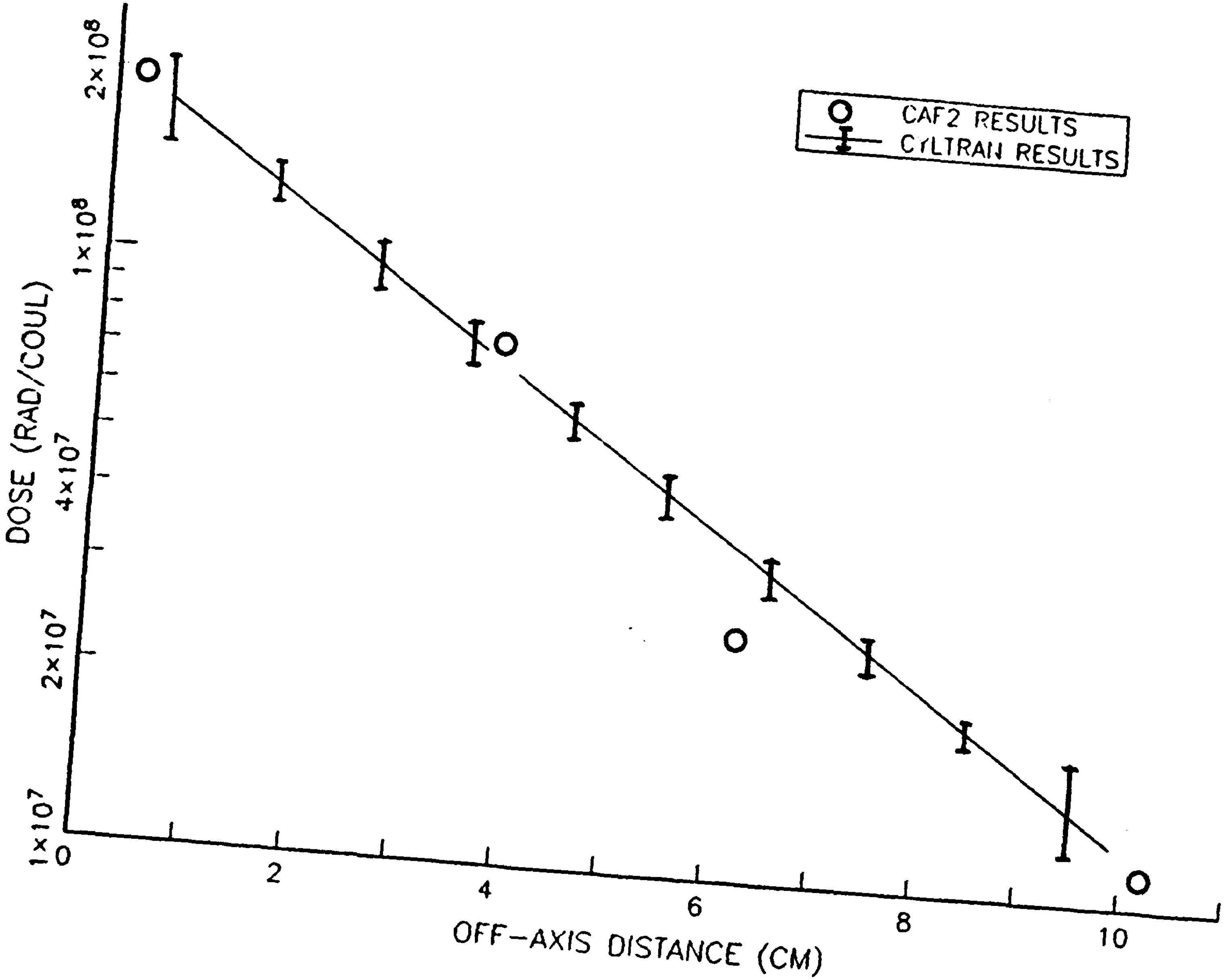
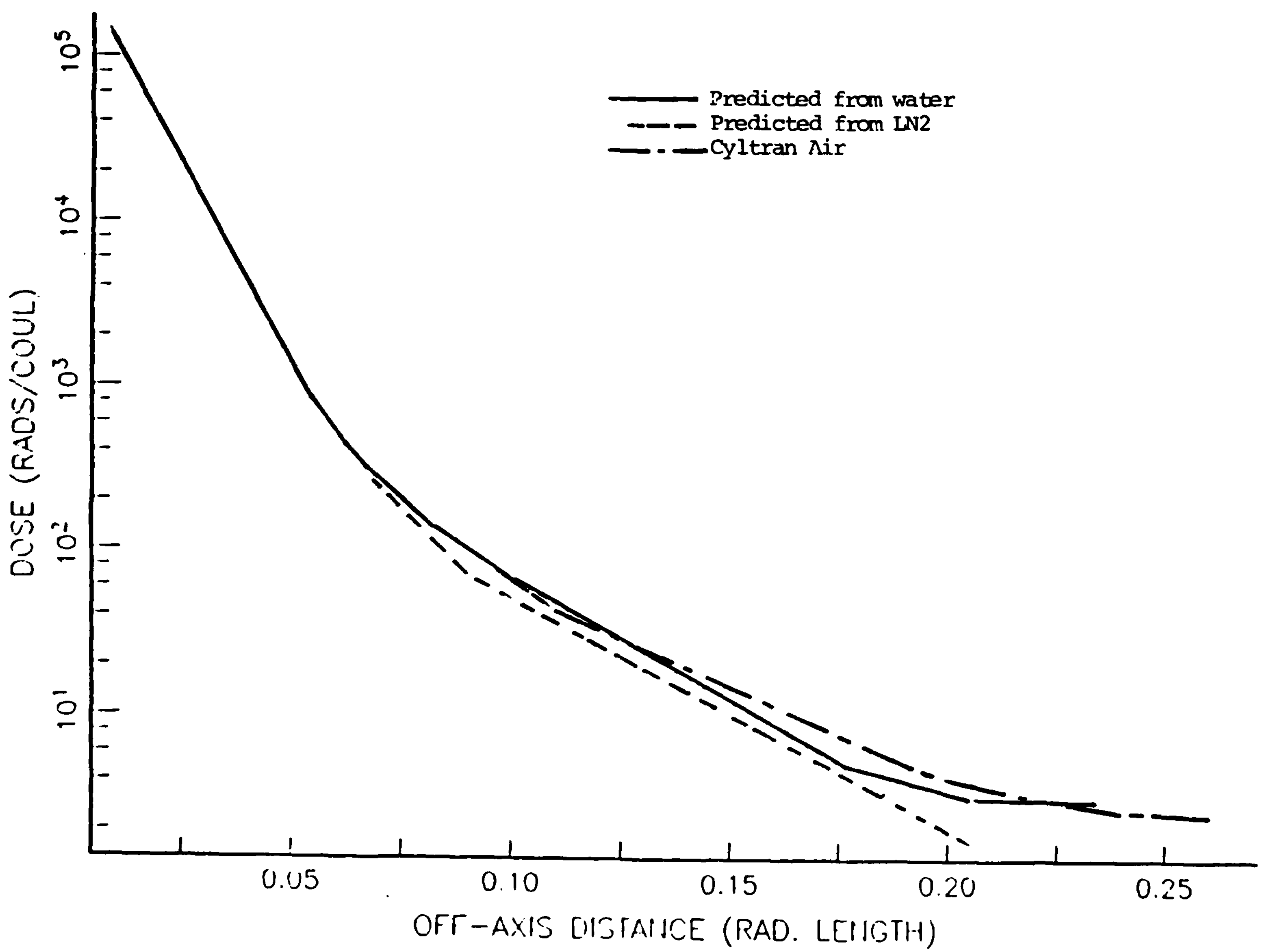

CAF2 RESULTS
CYLTRAN RESULTS
DOSE (RAD/COUL)
4×10^8
2×10^8
1×10^8
4×10^7
2×10^7
1×10^7
0
2
4
6
8
10
OFF-AXIS DISTANCE (CM)

Figure 12



CAF2 RESULTS
CYLTRAN RESULTS
DOSE (RAD/COUL)
2×10^8
1×10^8
4×10^7
2×10^7
1×10^7
0
2
4
6
8
10
OFF-AXIS DISTANCE (CM)

Figure 13



Predicted from water
Predicted from LN2
Cyltran Air
DOSE (RADS/COUL)
10^5
10^4
10^3
10^2
10^1
0.05
0.10
0.15
0.20
0.25
OFF-AXIS DISTANCE (RAD. LENGTH)

Figure 14

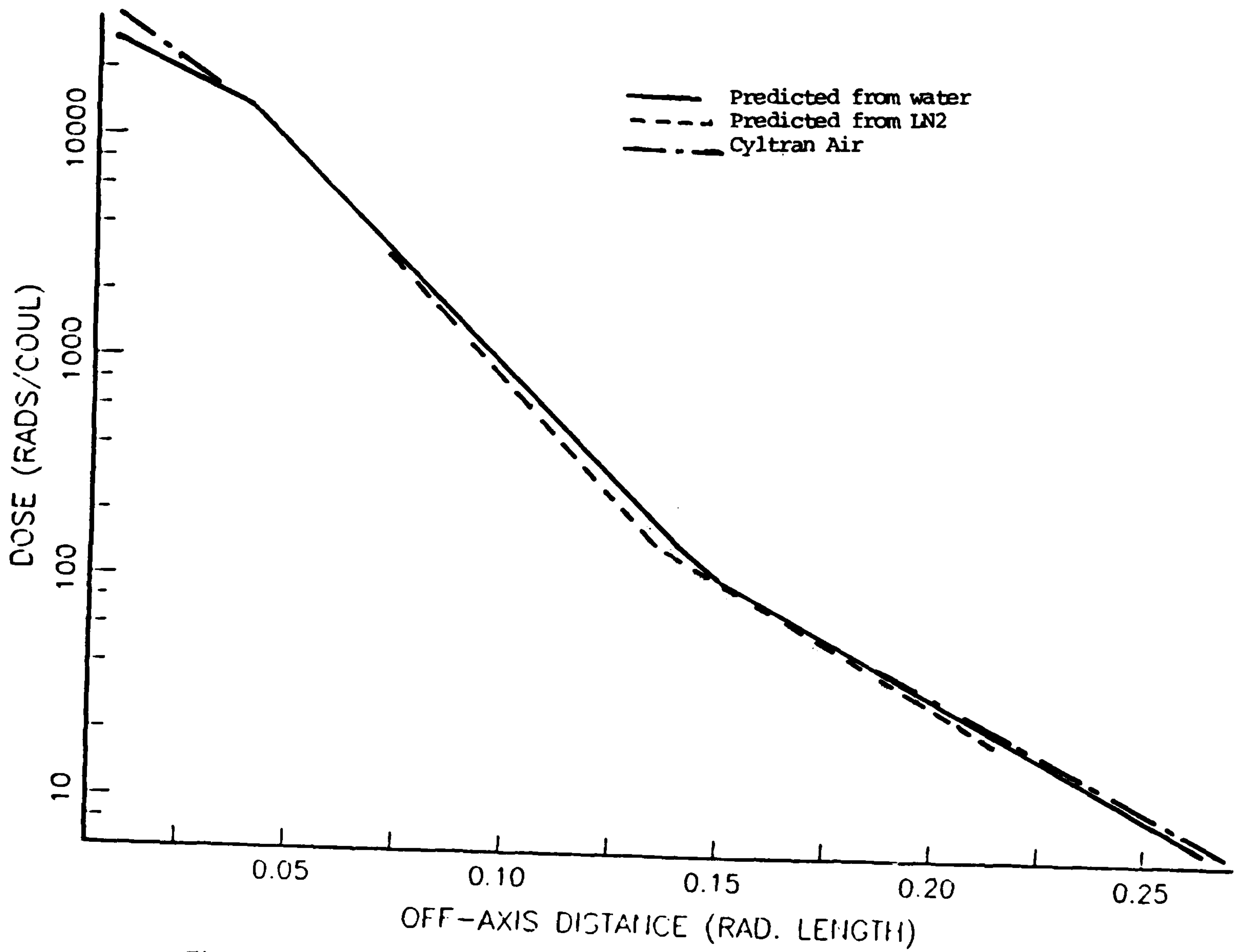
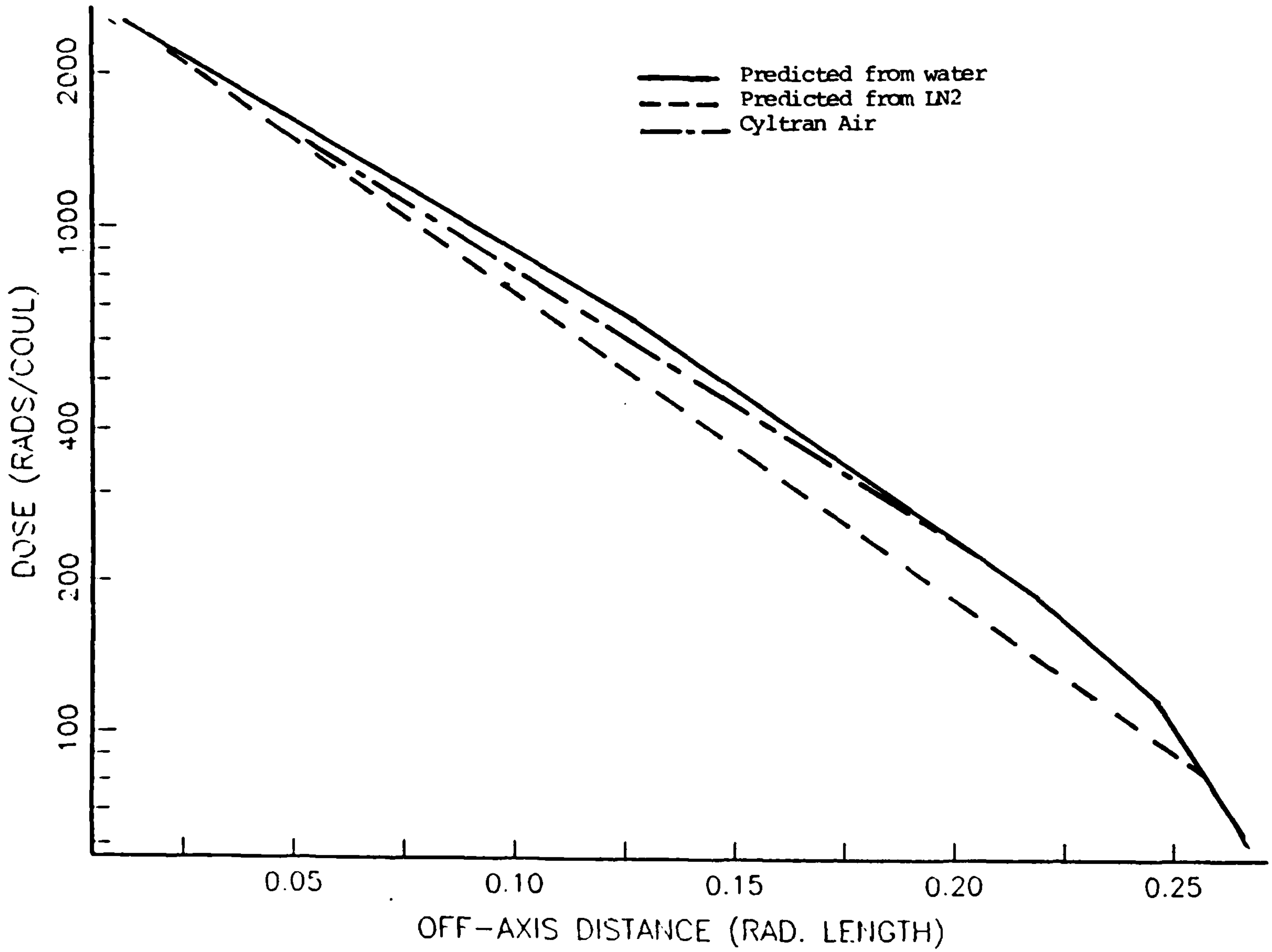

Predicted from water
Predicted from LN2
Cyltran Air
10000
1000
100
10
DOSE (RADS/COUL)
0.05
0.10
0.15
0.20
0.25
OFF-AXIS DISTANCE (RAD. LENGTH)

Figure 15



Predicted from water
Predicted from LN2
Cyltran Air
2000
1000
400
200
100
DOSE (RADS/COUL)
0.05
0.10
0.15
0.20
0.25
OFF-AXIS DISTANCE (RAD. LENGTH)

Figure 16

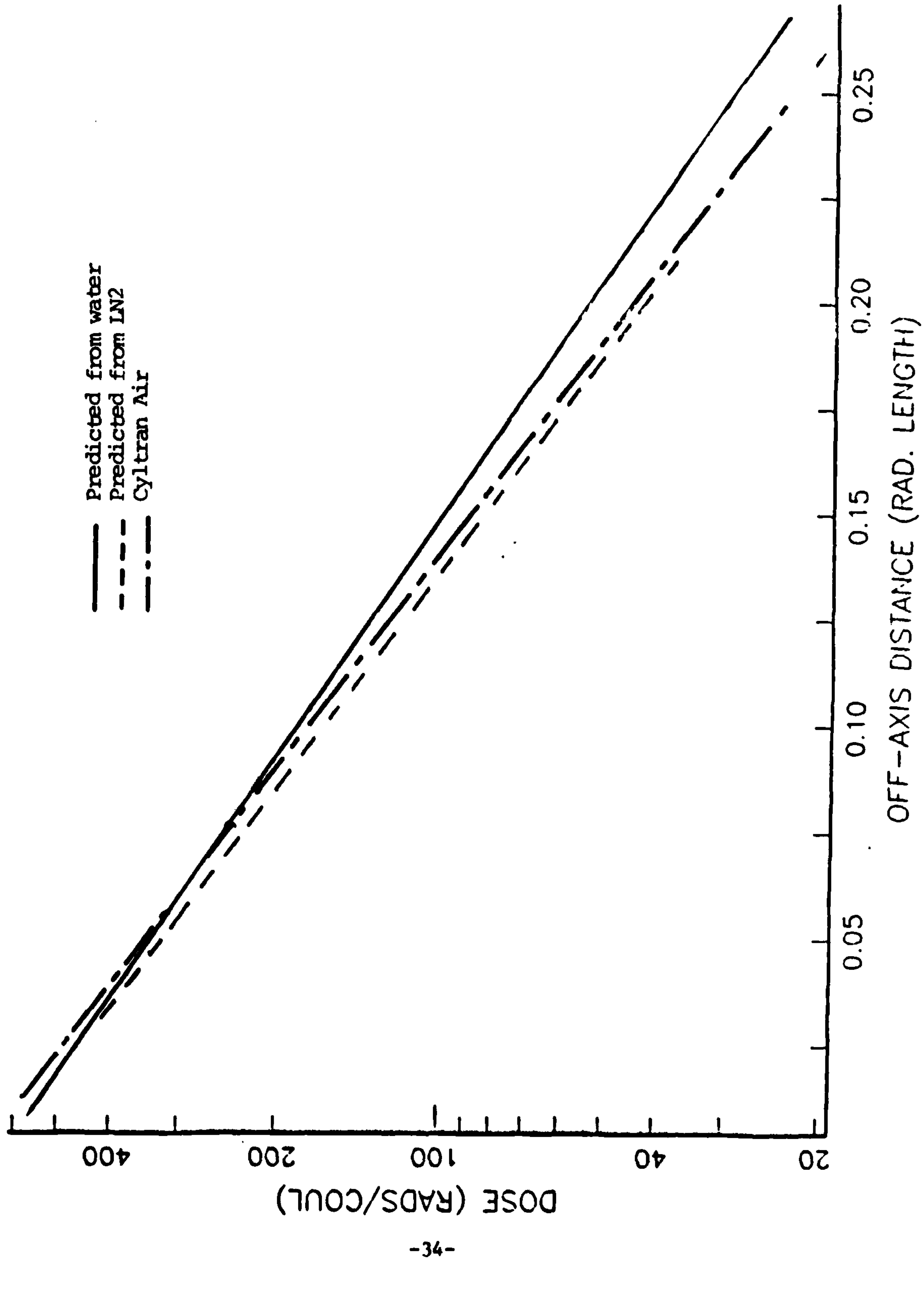

Predicted from water
Predicted from LN2
Cyltran Air
DOSE (RADS/COUL)
400
200
100
40
20
OFF-AXIS DISTANCE (RAD. LENGTH)
0.05
0.10
0.15
0.20
0.25

Figure 17

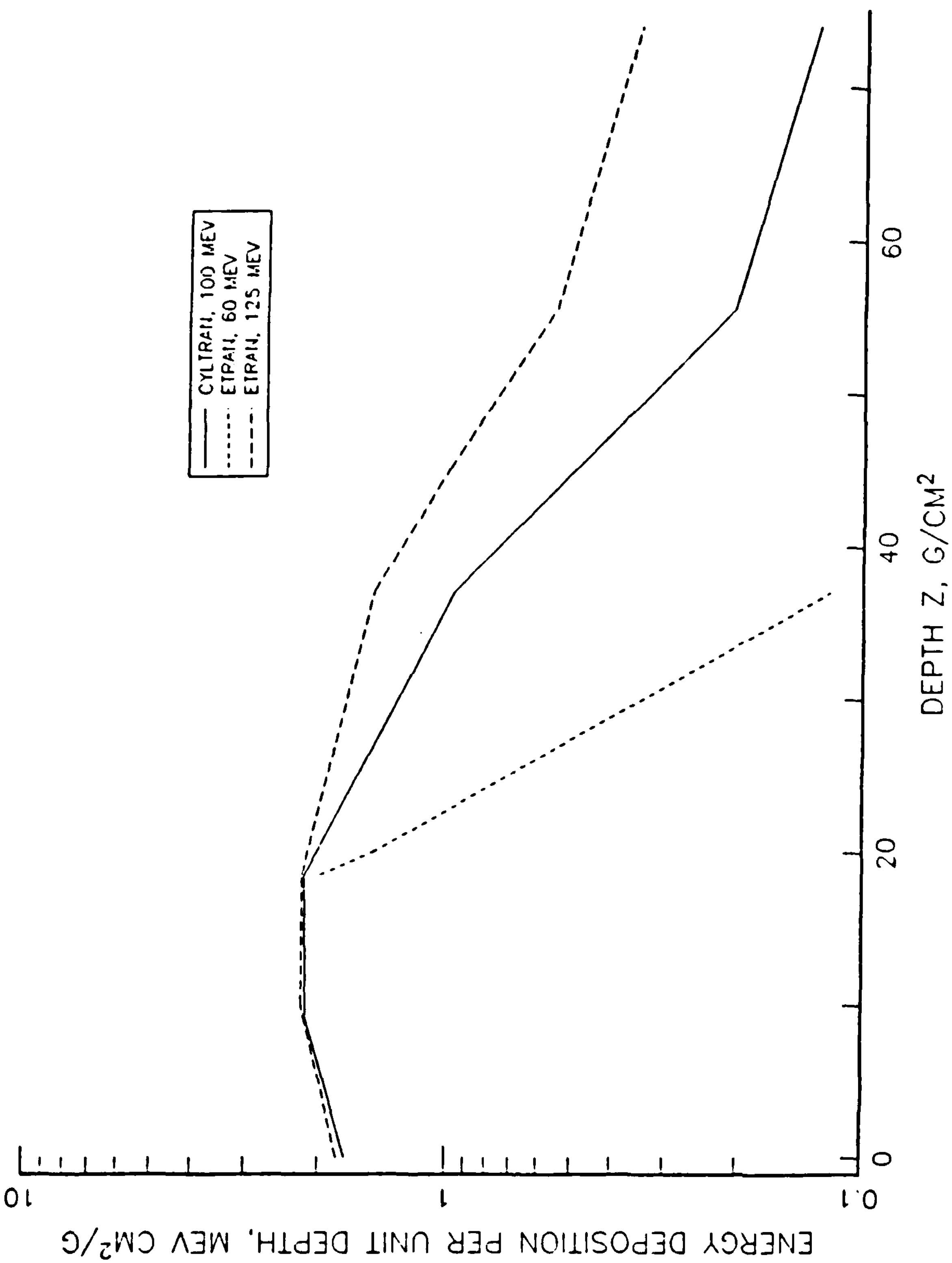

CYLTRAN, 100 MEV
ETRAN, 60 MEV
ETRAN, 125 MEV
DEPTH Z, G/CM²
0
20
40
60
0.1
1
10
ENERGY DEPOSITION PER UNIT DEPTH, MEV CM²/G

Figure 18

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M4, M.S. P-940
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PMS 405
Strategic Systems Project Office
Naval Sea Systems Command
Washington, D.C. 20376

Dr. R. Warren 1
Los Alamos Scientific Laboratory
P. O. Box 1663
Los Alamos, NM 87545

Prof. G. J. Yevick 1
Physics Department
Stevens Institute of Technology
Castle Point Station
Hoblken, NJ 07030

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